While the Occasionalists were unable to see how there could be any direct operation of the soul upon the body, they did evade both Physical Influx, which leads to materialism, and the theory of Pre-established Harmony, which leads to a concept of pre-destination. They needed a new concept of dualism; and this Swedenborg has supplied in his doctrine of degrees and his view of the relation of the spiritual to the natural as conatus is related to motion. From the religious aspect, the hypothesis of Occasional Causes is therefore relatively harmless. And this may help to explain why Swedenborg does not mind retaining the title "Occasional Influx" for Descartes' position, even though the later Cartesians used the term for their non-causal parallelism.

THE SHAPE OF THE EARTH

KENNETH ROSE

One of the earliest reasons presented to justify the launching of artificial satellites was their potential contribution to the science of geodesy. The shape of the earth has been measured by many different methods in the past, and each has shortcomings that have kept the most accurate determinations beyond man's reach. A close artificial satellite is capable of filling the void between measurements made from the earth's surface and those made by observations of celestial bodies. It gains perspective without losing proximity, and shows by its behavior in orbit the variations in the gravitational attraction acting upon it.

The first successful Vanguard satellite, 1958 Beta 2, has spent a year in an elliptical orbit that it traverses in a little over two hours. About four thousand times it has traveled from a position 400 miles above the earth's surface to another, 2500 miles up on the opposite side, and back again. Fluctuations in its orbit have demonstrated that gravity is not the same the world over, nor even a simple function of latitude. But through the inconsistencies there has been observed a persistent variation from the expected orbit, from which is inferred the first discovery in satellite geodesy: The earth is "slightly pear-shaped."

A geometer would recoil at this usage. Adjectives describing shape should not be modified or compared; either it is pear-shaped or it is not. What is meant, of course, is that there is a slight variation from the shape previously assumed, in the direction that would lead to the shape of a pear if the change were carried to excess. The adverb is quite necessary, since the variation amounts to something under fifty feet. Its most interesting feature is its asymmetry. The north pole is slightly higher than it should be, the south slightly lower. There is a zone around the south pole where the surface of the sea is some twenty-five feet above sea level!

This is by no means the first time the earth has undergone a profound change of shape. The first time it was recognized as an entity deserving a name of its own it was irregular in shape—a small, lumpy thing. It stayed that way for a long, long time before someone made it flat. Some observer before the dawn of history compared the domains that constituted various people's worlds, and noticed something that was constant throughout. From hill to valley to cliff to plain, there was some *je ne sais quoi* that remained unchanged. There was down. Then there were up and sideways, and the earth became flat.

Now, it may be argued that the earth was already flat, and that the discovery was a change in man's attitude rather than in the earth itself. It does not seem worthwhile to pursue this argument here. An earth no one knows is flat has a flatness as theoretical and useless as the sound of a tree that falls in the desert. Yes, the earth *became* flat just as surely as Columbus invented America.

Columbus was a key figure in the development of the earth's shape. The purpose of his journey was to make the earth round, and the new world interrupted his experiment. Magellan later finished the job, and the earth has been round ever since. These pioneers, however, did not make the earth spherical. Round, yes, but rather a cylinder than a sphere. For several centuries after their time the poles remained as inaccessible in practice as they are on a Mercator projection. There was no doubt in 1519 as to what was meant by going around the world. Magellan accomplished his goal by traversing 360° of longitude. The same thing can be done in a few seconds today by an imaginative member of one of the polar expeditions. But he would not win acclaim for it, because now that the earth is spherical it is a rather delicate problem to define its circumnavigation.

The transition from cylindrical to spherical was gradual and irregular. The *Nautilus'* transpolar voyage and the expedition across Antarctica, both during the International Geophysical Year, were significant advances. Air travel has rendered larger and larger portions of the surface spherical, although it may still be some time before it is generally accepted that Chicago and Calcutta are north of each other. The artificial satellites seem to be the first experiment so cosmopolitan as to call for a genuinely spherical earth, with a radius that enters into the calculations.

If Sputnik I made the earth spherical on October 4, 1957, it might also be said to have made it an oblate ellipsoid during the weeks following. The earth's 13-mile departure from the spherical is brought into stark reality by its effect on a satellite's orbit. It changes the direction of gravity's pull by an amount that would be negligible if it were not so patient. Bit by bit, a few miles per revolution, it makes the orbit precess in a way that must be considered by anyone who wishes to find the satellite.

And now another satellite has introduced what may be the final refinement in the shape of our planet. Not too much can happen after a fifty-foot variation from the "International Ellipsoid" of equatorial radius 6,378,388 metres and a flattening of one part in 297. Further refinements would be of smaller magnitude than the mountains and valleys that are regarded as surface features rather than as part of the shape of it all. The next shape for the earth might be the lumpy one, and bring the whole process back to its origin!

If the shape of the earth has been determined at last, who cares? Anyone can be casually interested in the characteristics of his own planet, but who has any vital concern with the shape of the earth to the extent of considering fifty-foot changes?

A very crude materialist might answer, "People who make globes." But he would be wrong. Undoubtedly there will be measurements made by satellites that will be of interest to the cartographer. But pear-shaped globes will never revolutionize the industry. Even the earth's oblateness is almost impossible to represent on any kind of scale model or diagram. A globe 16 inches in diameter uses a scale of 500 miles to the inch. The pear zones would be grossly exaggerated if represented by an extra coat of paint, since the deviation should be less than a fifty-thousandth of an inch. The equatorial bulge on the same size globe should appear as a disparity of a fortieth of an inch between the equatorial and polar radii. Indeed, the thickness of the material of which a globe is made is nearly always sufficient to encompass the bulge, all the lumps, and even the deepest mine and highest balloon ascent ever made by man. A relief globe, or even a relief map of a small region, exaggerates the vertical scale, sometimes tremendously, and gives a false impression about the earth's unbelievable smoothness.

The globemakers can never be so interested in the new shape of the world as are the geologists. The change not only adds an interesting tidbit to the knowledge of their subject, but opens some fascinating new questions. The pear shape demands explanation, whereas the bulge did not. The earth's oblateness might never have been discovered by experiment; it was reasoned that it had to be, because of the earth's rotation, and then measured as a confirmation. But the new asymmetry defies the laws of physics, or rather man's knowledge of them. The interior of the earth, it is argued, must be less fluid than has been thought, for this irregularity would require support of tremendous structural strength. Or, if the earth's core is still molten, as it was last year, it would seem to have great currents coursing through it that result in uneven support of the crust. (They would also support a recent theory about the origin of the earth's magnetism.)

The investigation of the earth's new shape will undoubtedly bring forth a wealth of geological knowledge, even if it turns out that the pearshapedness is not really there. This possibility must be kept in mind, especially when it is considered how wonderfully indirect the evidence is. The 6½-inch sphere that started this furor has been seen less than a dozen times. Its orbit has been analyzed from radio signals, so that it is to some extent a matter of speculation where the satellite is located. From this information there are several more steps to the conclusion that it is there because of an uneven shape. By the time the implication has reached from things seen and heard to the conclusion that "the shape of the earth is . . ." it involves a great many assumptions about the earth, its atmosphere and its gravity.

An old story illustrates the situation on a lower plane. In a modern setting, it would be a tale of a team of IGY scientists who came upon a woodsman's cabin in the course of investigating something else. They observed that the stove that warmed the shack was atop a four-foot log, and speculated on the physical and metaphysical reasons why the woodsman's unerring primitive instinct drove him to locate it thus. It is a long story, with a variable amount of detail in the discussion of convection, radiation, accessibility, fallout, etc. It ends abruptly with the recluse's coming upon the scene to point out that he didn't have enough stovepipe to reach the roof otherwise.

The scientists cannot be blamed for trying to find a more dignified explanation. They were acting as scientific philosophers, who cannot rest before an observed phenomenon is explained, or at least related to other observations. Such people as these should be the most interested in the shape of the earth. The history of the figure of our planet is a rather complete example showing how man's knowledge grows.

Important facts are not discovered instantaneously, but by a series of successive refinements. Even when one man manages to go far beyond his time in the recognition of truth, he can hardly accelerate the learning of mankind in general. Perhaps that is why Columbus had so much difficulty convincing his contemporaries that he was not about to sail off the edge of the world. For ten years he struggled to persuade the royalty of Portugal that the voyage would be of value, and then it was with great difficulty that he found a hundred men who would go with him. And yet he wanted only to demonstrate the truth of a theory that had been put forward two thousand years before! Pythagoras had guessed at, and Eratosthenes measured with incredible accuracy, the circumference of the obviously flat earth!

Why did it take so long to convince the world of something that is now so easily taken for granted? Possibly because of its apparent opposition to what is obviously true. The earth *is* flat. And it *is* all the other shapes it has ever been, simultaneously, today. For when truth develops through refinements, each version continues to be true forever. The new discoveries do not overthrow the old, but at worst place limitations on their application.

When the earth became flat it remained lumpy. To ignore its hills and valleys would be impractical in many obvious ways. But it would be very shortsighted to overlook the flatness simply because it was obviously not true. All the truth of plane geometry can be applied to a flat earth. It is the only kind for which maps can be drawn accurately, and the fact that maps cannot show hills very well does not outweigh the advantages they have.

When the earth became spherical it remained flat. Maps are still useful, and plane geometry still works, provided they be held to their proper limitations. The sum of the interior angles of a polygon the size of Alaska can be calculated from geometry, and would be in error by about two degrees. For smaller areas, the accuracy is better. Allowance for the earth's curvature in problems limited to small regions does nothing but confuse the issue.

The two descriptions of the earth become contradictory only at the insistence of someone who wants to overextend the earlier version. Two lines perpendicular to the same line are parallel *if* all three are in the same plane. This fact is learned without the last clause, and makes it difficult to believe that there are no parallel lines (great circles) on a sphere. *Everything else* about plane geometry does apply to the sphere if great circles are taken as lines, and might as well be used. But it is necessary first to overcome the natural reaction that spherical geometry is impractical and untrue because it opposes common sense. All that it opposes is plane geometry, and this only in one particular.

A similar example of a truth that has gone through refinements is the trajectory. A variety of ideas has been conceived about what a body does when it is given an initial velocity and is influenced thereafter only by gravity. Galileo settled the problem nicely by showing that the path it follows is a parabola, and this fact is now well known. But Newton refined the truth, showing that a trajectory is part of an elliptical orbit. Now, a parabola may be thought of as an ellipse with one focus infinitely distant. A Newtonian orbit for an object at the earth's surface is an ellipse with one focus four thousand miles away. If four thousand miles is infinite, the trajectory is a parabola.

It is interesting that the two unrefined truths, the flat earth and the parabolic trajectory, are compatible. A little integral calculus shows that a flat earth—of indefinite extent—would attract objects above it with a force independent of their height above the surface, and produce the uniform gravitational field that makes for parabolic trajectories.

People who live on flat earths can adjust only with difficulty to the existence of artificial satellites and rockets that escape the earth's gravity. This is only natural, since flat earths do not have such things. Once it is realized that all those parabolas are really ellipses, it becomes very believable that a satellite should "stay up" and an explanation must be found as to why one ever comes down. Galileo recognized the shortcomings of the parabola without even having Newton to tell him! In his *Mathematics of Motion* he explains that his earth is flat, and that he recognizes its limitations.

"The axis of the parabola along which we imagine the natural motion of a falling body to take place stands perpendicular to a horizontal surface and ends at the center of the earth; and since the parabola deviates more and more from its axis no projectile can ever reach the center of the earth or, if it does, as seems necessary, then the path of the projectile must transform itself into some other curve very different from the parabola."

This recognition of one's own provincialism is a rare quality in men, and seems to characterize the best thinkers of the ages. How many people are aware that every law they know is true only within the limits of measurable accuracy, and only under a more or less stringent set of conditions? It is unnecessary to be so aware while one stays within the domain where the law holds. The danger lies in going outside that domain and trying to extend the law beyond its capabilities. Facts that are true of every finite number, no matter how large, may yet collapse when applied to even the smallest of infinite numbers. Laws of physics that hold over the entire surface of the earth may even be transferable to the surfaces of other spheres and yet be meaningless in the asteroid belt. Some of the knowledges commonly accepted today may go so far as to hold true throughout the expanse of three-dimensional space, but still be stumblingblocks in the comprehension of a universe that is even now beginning to take on a new shape that transcends tri-dimensionality.

A temptation to which scientists have too often yielded is to try to overcome the mutability of truth by starting at the other end. They would take the latest refinement as true, and discard all that went before. Some people take an unwholesome delight in pointing out where Aristotle was wrong, or claiming that Einstein rendered Newton null and void.

But the scientist must not thus burn his bridges behind him.

The successive refinements of truth are the steps by which an individual acquires the learning of his predecessors. Educational processes accelerate the pace, so that he can imitate the progress of the whole human race and still have enough of his life ahead of him to proceed where others left off.

It may be attempted to omit the early steps of this process, and to present one of the refined versions of the truth as fundamental. The most notorious offenders in this are the authors of mathematics texts. Some think that recent developments in logic and set theory can replace first-grade arithmetic as an introduction to mathematics. Others, less radical, are still willing to offer general definitions (e.g., of the trigonometric functions), and then show what should be the early steps toward them as only special cases.

This sometimes seems to work. An artificial structure can serve the purpose to some extent, as can a manufactured antique. But there is a subtle danger that casts doubt on the desirability of going to all the effort required to start a process of refinement in the middle, and that is the risk of creating the impression that the middle is the end. There is no end to such a development. Unanticipated refinements may always follow "the last word" on a subject. It used to be possible to list all the fundamental particles of which matter was made, but it never will be again. The old lists must be retained if anyone is to have a basis from which to regard the complexities of nuclear physics.

So let us not be too eager to preach the doctrine of the pear-shaped earth. The older shapes are still indispensable in their places, and there are probably more surprises to come. Some experimenter in recent times coated a sphere of ice with paraffin. As the crust cooled and the interior melted, he saw ridges form on the surface in a pattern similar to that of the major mountain ranges of the earth. This may not mean anything at all. But, on the other hand, that ball of wax may prove to be the successor of the slightly pear-shaped oblate spheroid on which we live today.